

ELECTRIC VEHICLES IN CALIFORNIA: OFFSETTING INCREASED
ELECTRICITY DEMAND WITH PHOTOVOLTAICS AND ENERGY STORAGE

by

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I. Abstract

California has set a state goal to renewably generate 50% of its electricity by the year 2030. Although the state is currently on track to produce 30% renewable energy by 2020, this goal will become progressively difficult due to the states increased adoption of electric vehicles.¹ The rate of new vehicle registration growth for plug in hybrid electric vehicles and battery electric vehicles increased in 2016 to an average of 12%.² This increase in electricity demand will affect state generation capabilities and exacerbate existing electricity grid infrastructure concerns.

This report hypothesizes that electric vehicle penetration will continue to expand in the state, and makes the assumption that the state will have 12,807,387 electric vehicles which is the same number it currently has households. Using this assumed density of the state's electric vehicle market, this report will attempt to determine how this will impact the state's electricity demand, and how this changed demand can be offset in a sustainable manner through photovoltaic and energy storage solutions.

Given the constraints utilized in this study, the state's overall electricity demand would increase 14% with 12,807,387 electric vehicles which could be counteracted by installing 12 million 2.0kw photovoltaic systems residentially or of 232, 100 megawatt (MW) utility photovoltaic installations.³ California's infrastructure may be able to handle the demand from this increased electric vehicle density as proposed above, but it would not be able to accommodate this proposed photovoltaic load increase. To ensure the

¹ California's 2030 Climate Commitment

² US Tops 1% for EV Sales

³ PVWatts

existing grid remains functional, it is necessary to tie storage into the grid on either a residential or utility scale when adding any additional renewable generation sources. The state must furthermore continue to invest in incentives for electric vehicles, photovoltaic systems, and battery storage to ensure the aforementioned density of electric vehicles occurs.

Preface:

This thesis was written because of the author's interest with electricity consumption and generation in the state of California and nationwide. Renewable energy now has a noticeable impact on electricity generation and any change in the expected consumption levels directly affects the delicate balance currently reached between electricity consumption and renewable generation sources.

Electric vehicles have been touted as the future of the transportation sector due to their high miles per gallon equivalent and their ability to be charged on renewable energy which negates any carbon emission release. This evolution of the vehicle market will have unintended repercussions and this Capstone explores just one of them: increased electricity use. This report will examine how electricity patterns will change in the electric vehicle future, and what must be done now in order to prepare it.

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I. Introduction

This report aims to identify the ways in which CA will need to adapt its existing relationship with renewable power and energy storage to meet its proposed increased electricity consumption and generation habits. California is consistently a leader in the United States for environmental policy and has also proven to lead the world because of its far reaching economic power.⁴ Due to these influential capabilities, the steps the state takes to adopt electric vehicles and preserve the integrity of its electrical grid are especially significant.

To determine the state's future electricity demand due to the increased density of electric vehicles, this report made the assumption that the density of electric vehicles is equal to one electric vehicle per household as defined by the California State Census. This assumption was generated as a measurement tool due to homeowners expected socioeconomic status and ability to install residential charging stations. Given existing data about the state's current electric vehicle density and the number of vehicles purchased annually in the state, this projected density will not occur until after 2081. (Appendix: Extrapolated Data) These numbers are based on figures that have wide variability however, including the number of new vehicles purchased a year, the percentage of electric vehicles purchased and the number of internal combustion engines that are retired annually.

Utilizing this assumed density of electric vehicles as well as data pulled from the two largest utilities in the state, Pacific Gas and Electric Utility (PG&E) and Southern

⁴ Vogel, David

California Edison Utility (SCE), this report will examine the impacts from this electric vehicle fleet and what must be done to safeguard the electric grid's functionality. This report will further explain how the increased electricity demand can be offset by photovoltaic power on a residential and a utility scale. The data will identify the state's future electricity needs, and this report will go into further detail to explain how photovoltaic installations and home storage units can be used to assist utilities in increasing electricity generation. This report will also examine how the use of energy storage can smooth out residential electricity demands to simplify utility generation habits.

II. Methods

Electricity

Using the aforementioned assumption that the state's electric vehicle density as equivalent to one electric vehicle a household, this report relied on data from the 2016 State Census to establish the number of households in California. Information from the US Energy Information Administration (EIA) provided the amount of electricity California uses annually per sector and in totality along with information on electricity consumed for the US overall. Population information from the EIA was also used to determine the state and country's per capita electricity usage. (Appendix: Electricity Patterns)

The Department of Transportation (DOT) provided information on the number of vehicles in the state, the number of miles travelled annually and the average miles per gallon (MPG) of the existing CA fleet. To ascertain the amount of electricity needed to

charge one electric vehicle annually based on the average number of miles Californian's travel, the highest selling electric vehicles from 2017, the Chevy Bolt and the Tesla Model S, were examined for their watts necessary per mile.⁵ Utilizing public information on these two electric vehicles, it was possible to determine the average watts needed for the vehicles to travel one mile and therefore how much electricity would be necessary to drive the average number of miles for the state. (Appendix Extrapolated Data)

Information from the Tesla Model 3 was also utilized due to its lower price point and its reservations for the state which out number the sales of the Model S.⁶ (Appendix: Extrapolated Data).

The information gathered regarding the vehicles was compared against the state's average MPG and the highest selling vehicle in 2016, the Honda Civic. The information on these vehicles determines the difference in consumer fuel cost, and carbon emissions avoided.⁷ (Appendix Extrapolated Data) Furthermore data on future MPG rates and the effect that electric vehicles would have on state MPG and carbon emissions was calculated to determine the environmental benefits of electric vehicles versus internal combustion engines.

To calculate the cost associated with fueling the electric vehicles, PG&E and SCE's electric vehicle rate plan was examined.⁸ All rate plan pricing data was determined assuming that consumers charged their electric vehicle only at their residence

⁵ Baker, David R.

⁶ Tesla Model 3 - Estimating the Total Reservations per Country

⁷ Nikolewski, Rob

⁸ Pacific Gas and Electric Company & Southern California Edison

and only during off peak times. For combustion vehicle comparisons, gasoline prices were taken from AAA from the month of February 2018.⁹

The amount of carbon dioxide California could avoid if its existing vehicle fleet had 12,807,387 electric vehicles was calculated given the number of miles traveled by the average vehicle per the DOT. Using a formula utilized by Dr. Austin Brown in the Johns Hopkins class Transportation Policy in a Carbon Constrained World Spring 2018, this report was able to calculate the state's new MPG if the existing fleet contained as many electric vehicles as households. It was further estimated based on US vehicle purchase records from 1980-2015 what percentage of the country purchases vehicles a year.¹⁰ This percentage was applied to the estimates in California's population growth from the DOF to determine how many new vehicles were purchased a year. The DOF also lists population and household by county which was utilized. (Appendix Extrapolated Data)

This data requires additional studies to determine the actual rate of vehicle retirement in the state as well as what percentage of vehicles purchased are new or used. This is a strictly preliminary number and does not claim to be wholly accurate. Along with this vehicle purchase rate assumption is the calculation of the state's new MPG which relies upon the state's current MPG and an annual increase derived from the California State Board of Equalization(CSBOE)¹¹.

This report by the CSBOE states the country's MPG as 17.0 miles in 2013 and 17.5 MPG in 2010. Using this annual increase of .42%, this report estimates the state's

⁹ AAA

¹⁰ Statista 2018

¹¹ State Board of Equalization

increase in MPG and can therefore calculate the effect of electric vehicles on the state's MPG and carbon dioxide emissions for the year when the density of electric vehicles equals the number of households in 2081. Though this calculation takes into consideration the estimates of the California population, it does not take into consideration any increase in households that most likely would occur along with the population growth. This report simply analyzes the existing knowledge about California's vehicle fleet to determine at what year this hypothesis of equal electric vehicles and household numbers might come to fruition. (Appendix: Extrapolated Data)

Photovoltaics

With the new electricity demand calculated, it was possible to determine how much electricity each home would need to generate to offset their increased electricity usage. This was calculated three different ways: estimating that each home would only produce enough electricity to offset their individual electric vehicle usage increase, estimating how much electricity each home must generate to offset the total additional power increase given the state's existing photovoltaic households, and finally estimating how much electricity the utilities would need to generate to offset the state's total increase. (Appendix: NREL Data)

Data from California Distributed Generation Statistics (CDGS) was utilized to determine the number of residential solar installations in each utility.¹² It was then calculated as a density percentage based on the percentage within the state given its population. For example, PG&E states that it serves 16,000,000¹³ of the states 39,250,017

¹² California Distributed Generation Stats

¹³ PG&E

population.¹⁴ This is 41% of the state's population. Therefore, the number of households in PG&E's service range is 326,296, or 41% of the total 12,807,387 households in the state. (Appendix: Extrapolated Data)

Using those numbers and the number of actual residential households with photovoltaics already installed, PG&E's residential solar density rate could be discovered and averaged with the density rate from SCE to determine an estimate of the state's overall residential photovoltaic density percentage. Because of this, not every home would get photovoltaic as some had already done so previously, meaning that the number of homes eligible for photovoltaics is less than the number of homes that have theoretically acquired an electric vehicle.

The National Renewable Energy Laboratory (NREL)'s PVWatts calculator was utilized to determine average solar system size for the three scenarios proposed above¹⁵. This information was calculated based on the city of Fresno due to its central location in the state. NREL specifically estimates an average efficiency loss of 14% due to inverter conversion efficiency, soiling, shading and miscellaneous inefficiencies. (Appendix: NREL Data) Electricity generation data was also extracted from the CDGS on a per county level. For each county, the amount of generation was calculated by the system sizes and expected annual solar radiation of 5.8kw/m² per NREL.¹⁶

Storage Systems

¹⁴ QuickFacts

¹⁵ PVWatts

¹⁶ PVWatts

To compliment the photovoltaic installation, storage was also analyzed on a residential and utility scale. Storage calculations were estimated based on the number of households that are estimated to install photovoltaics to offset their electric vehicle electricity usage. The electricity storage information utilized is pulled from public data on the Tesla Powerwall due to its 67% dominance in the residential storage market in CA.¹⁷ Solar system size is estimated to be the same for each home and due to the inability to share Powerwalls between residences, each household was assumed to accommodate one home storage battery. (Appendix: NREL Data)

III. Results

Electricity

Through the use of the Methods section described above, the amount of additional electricity needed in the state due to the addition of one electric vehicle per household is 36,881 gigawatt hours (GWh) a year. The amount of residential power consumed by CA was 88,311 GWh in 2016 and this plus the 36,881 GWh increases residential demand by 42%. State wide however, California's consumption would increase by 14% which would bring the state's overall consumption to 293,728 GWh annually. (Appendix: Extrapolated Data) These calculations were made with the assumption that no additional energy efficiency would take place in the state and uses the state consumption totals from 2016 despite the fact that this density of electric vehicles would not occur until much later.

By charging the vehicles at off peak times on the electric vehicle rate plan for PG&E and SCE respectively, a consumer's average fuel cost is around \$390 annually. By

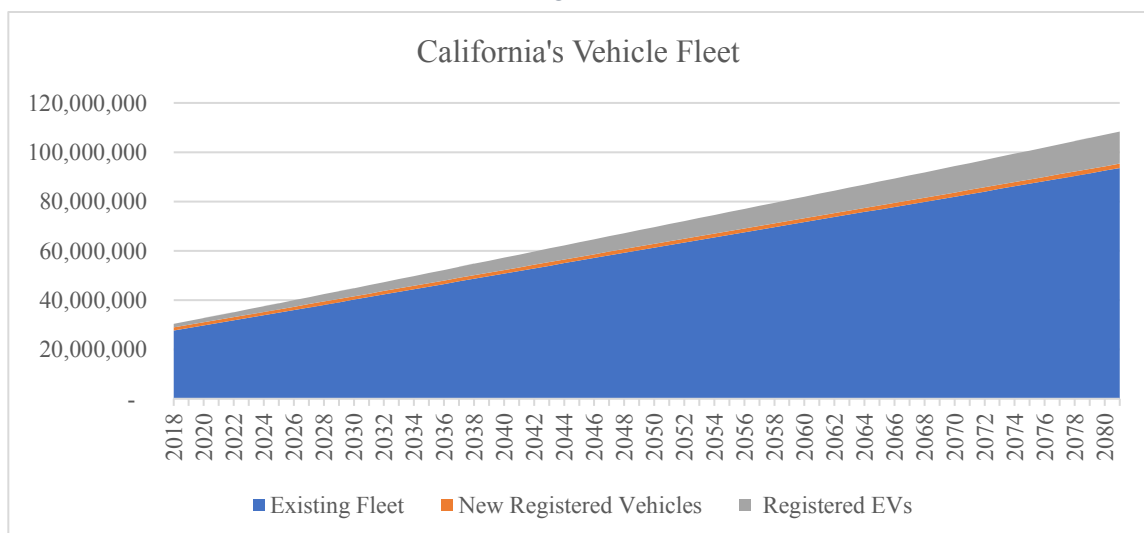
¹⁷ Program Metrics

proxy, a Honda Civic driver would spend \$1,091.49 on fuel cost annually. The existing vehicle fleet in California has an MPG of 18.02 miles and would therefore spend about \$2,059.41 annually on fuel. These numbers were calculated based on data from the DOT for which the state's average MPG is not specified as to commercial vehicles versus residential. For the purposes of this report, it is assumed they reflect residential vehicles. (Appendix: Extrapolated Data)

If California's existing vehicle fleet were made up of aforementioned 12.8 million electric vehicles that were all powered renewably, the state's MPG rating would increase from 18.02 MPG to 29.75 MPG and the state would save over 70 million metric tons of carbon dioxide annually. (Appendix: Extrapolated Data) To determine what year the state would eventually achieve the density of one electric vehicle per household as estimated in this report, information on the existing number of electric vehicles in the state and their expected growth patterns was utilized to project future trends.

Since 2013, the annual percentage of new vehicle registration has been about 9% for electric vehicles increasing to 12% for plug in hybrid electric vehicles and battery

Figure 1



electric vehicles in 2016.¹⁸ California's current fleet is about 5% electric vehicles.¹⁹ Further data based on the number of new vehicles purchased a year in the United States divided by population provided the average percentage of consumers who purchased new vehicles. This data was applied to the growing CA population to determine the number of vehicles purchased overall and the number that were electric vehicle based on the earlier stated 12% expected growth rate. (Appendix: Extrapolated Data) Given these constraints, it is estimated that California will reach the density of one electric vehicle per household by roughly 2081: see Figure 1. (Appendix: Extrapolated Data)

Using the state's current MPG and the expected annual increase as stated in the Methods section, this report was able to calculate the new state-wide MPG rating in 2081 to be 23.47 if current growth patterns remain. This report is assuming more electric vehicles are purchased annually which would directly affect the state's MPG. However, if current MPG increases remain consistent, the state's vehicle fleet would increase to about 93.5 million vehicles with an MPG of 23.47 miles by 2081.

The MPG for the Chevy Bolt, Tesla 3 and Tesla S average 116 MPG which if combined in number with the total number of non-electric vehicles in the state in 2081 would increase the state's MPG rating from 23.47 miles to 25.99 miles. This would save the state over 54 million metric tons of carbon emissions. This number contains many variables including the number of electric vehicles purchased a year as well as the number of combustion vehicles retired annually. It is expected that fewer combustion engines will be purchased each year in the next 100 years as more manufacturers produce

¹⁸ US Tops 1% for EV Sales; California Edges Toward 5%.

¹⁹ Klippenstein, Matthew

hybrid and electric vehicles, so these numbers will shift as those percentages do.

(Appendix: Extrapolated Data)

Photovoltaics

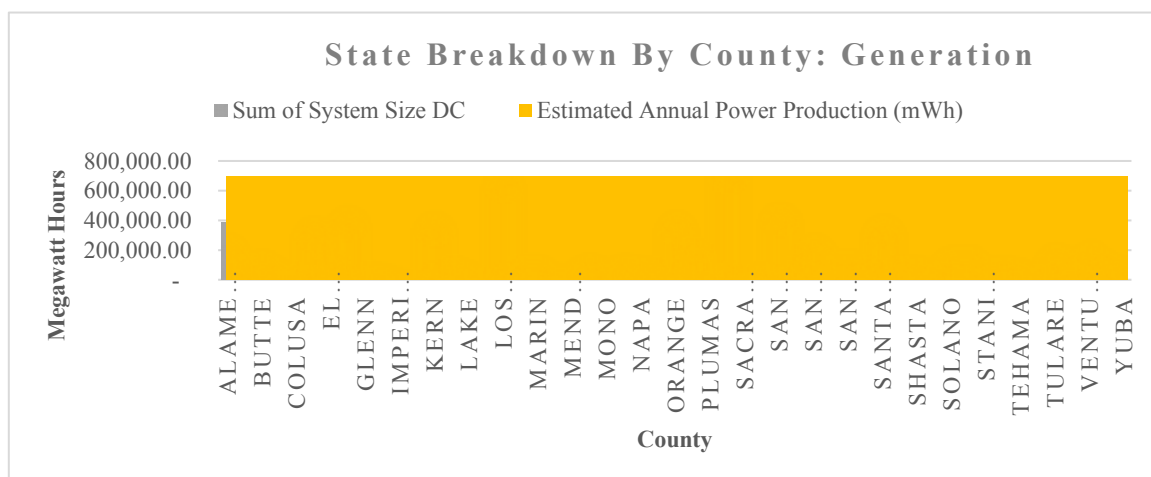
Utilizing the 36,881 GWh needed annually to offset the electric vehicles added to the state's fleet, it can be estimated that each home without photovoltaics would need to install a 2.0 kw photovoltaic system to offset this electricity. This size system accounts for an existing solar density of 5.6% in California and assumes that the households that have gone solar already do not install an additional system. (Appendix: Extrapolated Data) If the remaining households without solar were to install a 2.0kw system respectively, they would produce roughly 3,180 kwh annually and generate enough power to offset the total additional electric vehicle consumption. If the homeowners were to install a photovoltaic system to offset only their specific electric vehicles consumption, they would need a system size of 1.85kw and would generate 2,941 kWh annually as compared to the annual demand per electric vehicle of 2,880 kWh. (Appendix: NREL Data & Extrapolated Data)

This is using the assumption that the homeowner drives the estimated annual miles by the state and does not take into consideration variable driving habits or varied commute distances. For this report, it is assumed that every home has the ability to install a photovoltaic system due to the wide number of products available to the residential market including ground mount photovoltaic systems, solar roofing, tracking photovoltaic systems, and roof mounted photovoltaic systems.

If utilities were to offset the increased consumption, they would need to install 232 100MW photovoltaic systems in order to generate the amount of electricity necessary to offset 36,881 GWh annually. (Appendix: NREL Data) This represents the total amount of photovoltaic systems necessary for the state but does not take into consideration the number of utilities in the state or the availability of land necessary to install this number. Conventional knowledge suggests that 100 square feet are necessary per 1kW of installed photovoltaic systems.²⁰ Given this measurement, utilities would need to utilize 2.3 trillion square feet or 83 square miles to install this size photovoltaic systems. For comparison, the state of CA is made up of 155,959 square miles in total.²¹

CDGS provided county specific data on the number of photovoltaic systems that have received interconnection in PG&E and SCE territory.²² This data was combined with population and household information from the DOF as seen in the Figure 3.²³ Using the combined photovoltaic system sizes per county, this report was able to calculate the amount of electricity currently generated per county and compare it to the

Figure 2



²⁰ NW Wind & Solar.

²¹ Fast Facts Study Guide (State Areas)

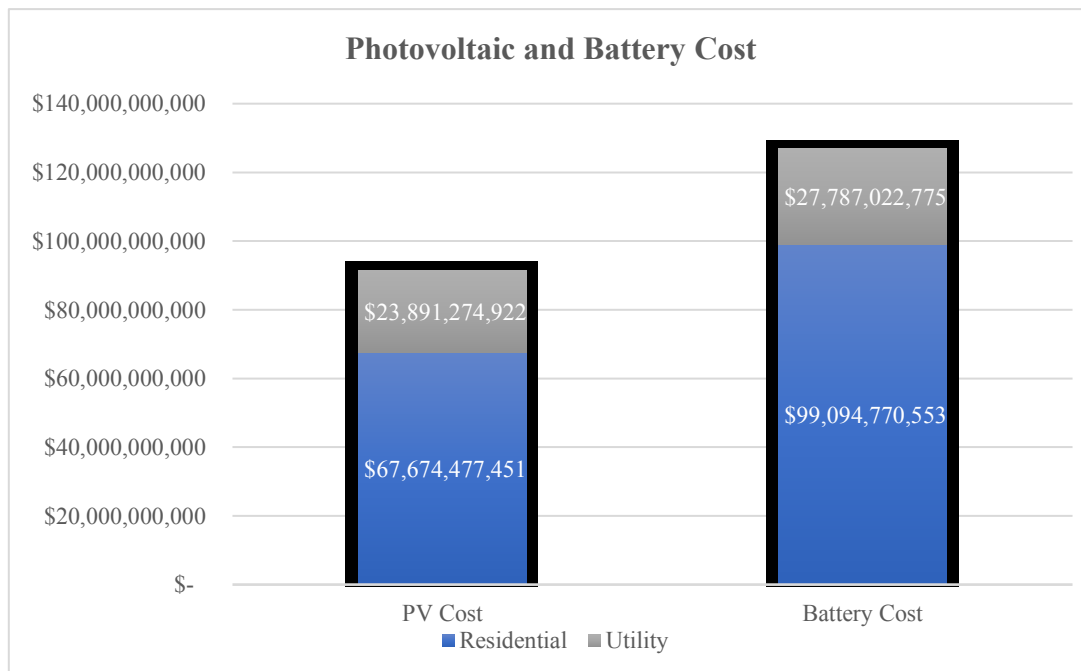
²² California Distributed Generation Stats

²³ Department of Finance State of California

its current struggles to manage its renewable energy generation, adding 12 million photovoltaic systems would necessitate the installation of 12 million electricity storage units.

This increase in storage would create the ability to store and utilize 59,547GWh hours annually if the storage were added strictly to new photovoltaic systems or 67 % of the existing residential consumption. If one battery storage were added to each of the 12.8 million households and utilized daily along with a photovoltaic system, it would reflect an ability for the state to store 63,108GWh annually or 71% of the state's residential demands. (Appendix: Extrapolated Data) This volume discussed would allow for the state's electrical grid to remain unchanged as it would not have to increase its load capability to manage the increase in demand and residential generation. The introduction of this many storage units would assist in addressing existing shortcomings of the grid as

Figure 4



discussed later in this report.

When examining the cost for both of these to the state, it is clear that the burden falls heavier on the residential consumer than the utility. NREL states that the cost for photovoltaic systems in CA is currently \$2.80/watt to build a residential photovoltaic system and \$1.02/watt for utilities to build.²⁵ In the same manner, the price for residential battery storage is about \$600/kwh and for utility storage is about \$275/kwh.²⁶ These numbers are the cost to build the equipment and do not reflect any price mark ups to account for installer profit. Furthermore, these numbers do not reflect any cost to install additional transformers or grid lines that may be necessary to tie solar installations into the existing grid. The two costs in Figure 2 are strictly for the photovoltaic and storage equipment. Using these two measurements, it is clear that the cost for utilities to renewably offset this increase in electricity is more cost effective. See Figure 2 for more details. (Appendix: NREL Data)

IV. Analysis

Electricity

The DOT estimates that there are 27,697,923 registered vehicles in the state of California and

that annually
these vehicles
drive

Figure 5

Make	Chevy	Tesla	Tesla
Model	Bolt	S	3
Price	\$ 36,620.00	\$60,200.00	\$35,000.00
Battery size (kWh)	60	75	52.5
Range (miles)	238	259	220
kWh/mile	0.25210084	0.290	0.239
Wh/mile	252.1008403	289.58	238.64
miles/ gallon equivalent	119	103	126
Average Wh/mile		260.10	

²⁵ National Renewable Energy Laboratory

²⁶ Nykvist, Bjorn

306,649,000,000 miles or 11,071 miles. According to the DOT, the state's average vehicle MPG rating is 18.02 miles.²⁷ The electricity usage and miles driven for the state of California utilized an average of Tesla Model S, Tesla Model 3, and the Chevy Bolt which can be found below and in the Appendix. See Figure 5 for more information. (Appendix: Extrapolated Data) The MPG impact on the states average MPG was discussed in the Methods and Results section of this report. Though the influx of electric vehicles would increase the state's electricity usage, it would also decrease the state's transportation emissions providing additional benefits to the state.

As previously discussed, CA is committed to generating 50% of its electricity renewably by 2030. The state's goal is tied to overall carbon emissions as addressed on their website, "Using renewable resources could help reduce emissions from the transportation sector as increasing numbers of Californians drive electric vehicle, as well as from electricity use in the residential, commercial, and industrial sectors."²⁸ The numbers calculated in this report validate the state's assumption that as electric vehicles and renewable generation increases, overall state emissions decrease.

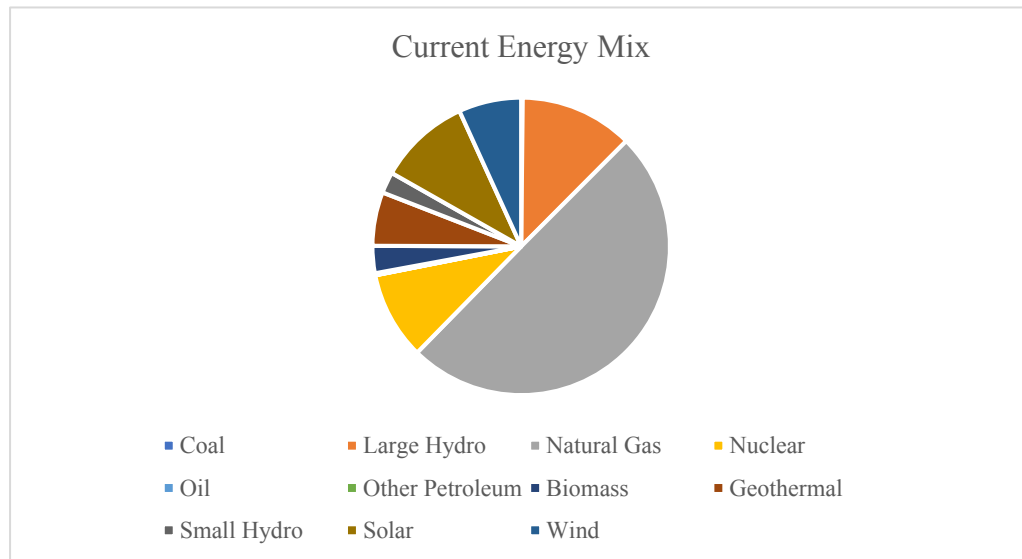
California plans to achieve these goals through the addition of renewable portfolio standards, state wide incentives and the implementation of friendly renewable energy policy. By December of 2017, California had already installed more than 17,210 MW of large scale renewable energy comprised of solar, wind, biomass, geothermal and small hydropower. Small-scale installation of renewable energy had reached 10,520 MW by the

²⁷ Federal Highway Administration

²⁸ California's 2030 Climate Commitment

end of 2017 with the vast majority of it being photovoltaic power (8,600MW).²⁹ Figure 6 shows the state's current breakdown in energy generation.

Figure 6



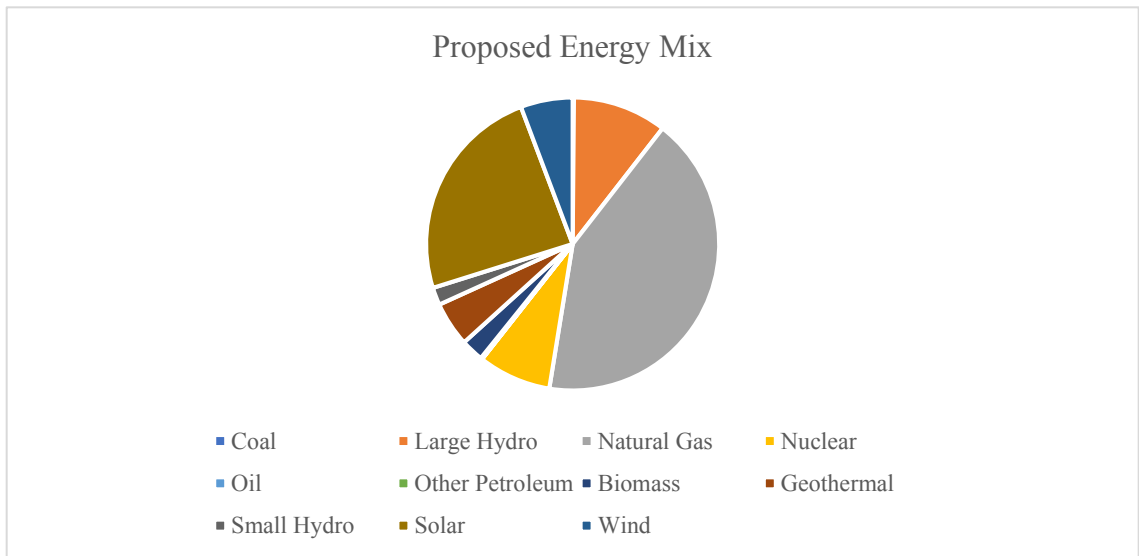
Photovoltaics

In order to offset the electricity utilized by the growth of the electric vehicle market, residents and utilities will need to invest in distributed generation and storage methods. To determine the energy mix of the state assuming the install of photovoltaics to offset the increased demand photovoltaic data was added to the state's existing energy ratios. California's current renewable numbers are reflected in Figure 6.

If the state were to install 2 kw photovoltaic systems on each household without an existing photovoltaic system, it would change the states generation source percentages. Figure 7 represents that change.

²⁹ California's 2030 Climate Commitment

Figure 7



Storage Systems

The installation of 12,084,728 residential batteries into the electric grid would increase its stability as it allows households to pull power from their batteries to charge the electric vehicles instead of pulling the extra energy out of the grid. It may also allow for steadier home energy consumption as will be mentioned in the Discussion section of this report. Existing electrical infrastructure would be able to accommodate the increase in electricity demand by but would not be able to accommodate the increased amount of photovoltaic generation. Even without the suggested influx of electric vehicles and photovoltaics, the state of California needs to invest heavily in electrical storage in order to maintain its existing infrastructure given the expected increase in renewable generation per the state's goals.

As discussed in the Results section, this change in density of electric vehicles will most likely not occur until on or after the year 2081, however the state must prepare now

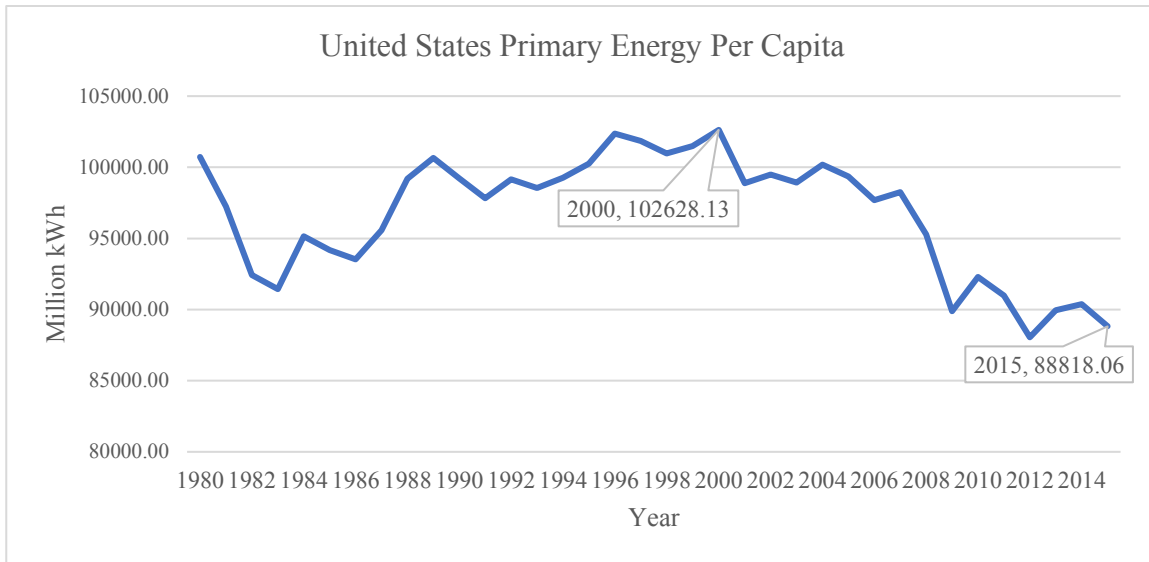
for the shift in electricity usage. California leads the United States' renewable policies and the measures it takes to safeguard its electrical grid and its renewable power generation will be used as examples for others. The changes to the electrical grid take time to research and correctly address. Therefore, the state must begin writing policies now continue incentivizing consumers and utilities to install battery storage in anticipation of these changes. Though the time frame for these changes may end up being different for the time line as calculated in this report, the increase of electric vehicles is undeniable.

V. Discussion

Electricity

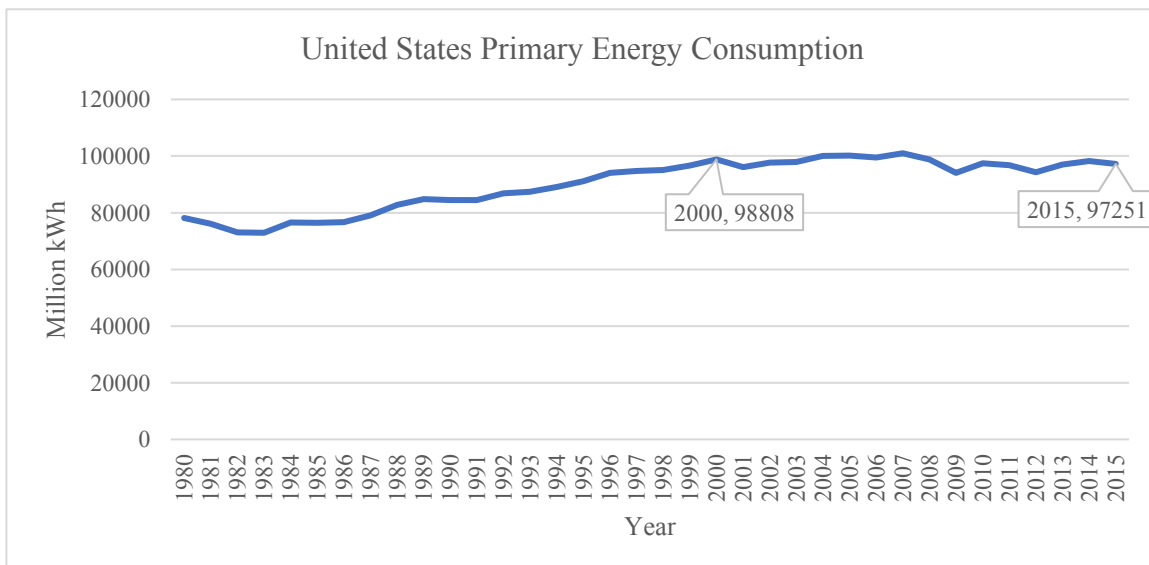
The increased electricity demand in CA due to electric vehicles is important because of the state and country's electricity consumption history. Over the past three decades, the United States has decreased the amount of electricity consumed per capita due to increased energy efficiency and conservation efforts. Per Figure 8 and 9 seen below, the US consumed 100.723 billion kWh per capita in 1980 and 88.818 billion kWh per capita in 2015. Furthermore, the overall electricity consumption for the United States has stayed roughly flat for about 15 years despite the increasingly profitable economy. See additional details on United States energy consumption patterns from the Energy Information Administration in Figure 8 and 9.

Figure 8



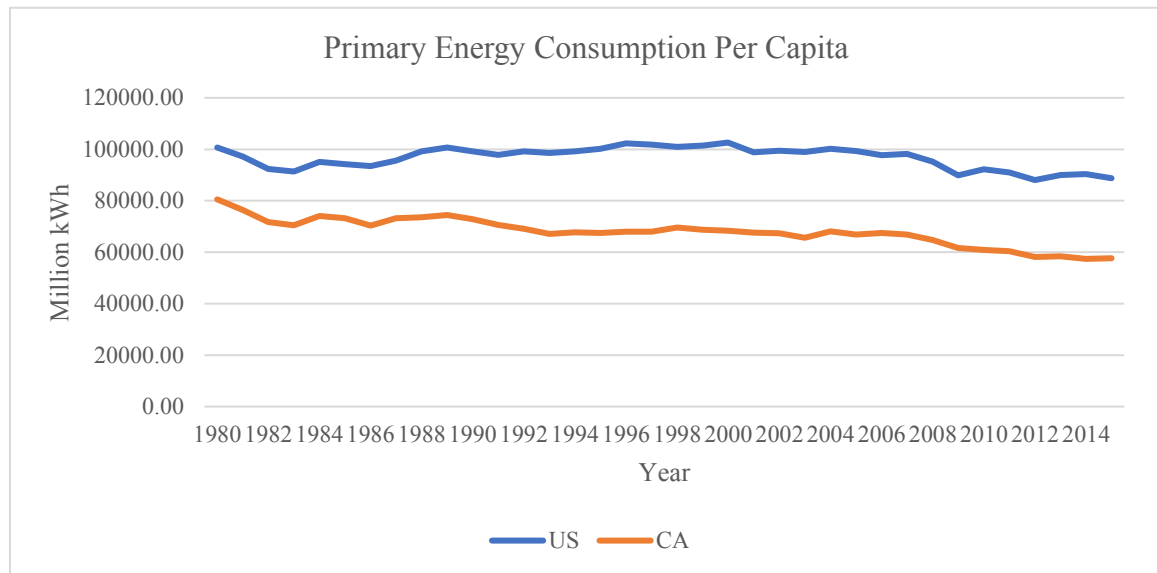
California's electricity consumption patterns mimic the United States' as discussed above. Though the population continues to rise, the overall primary electricity use has stayed consistent and electricity consumption per capita has declined. Due to this, California should be able to more easily reach its renewable energy goals. However, the state is steadily electrifying its transportation sector and reaching 50% renewable

Figure 9



generation by 2030 electric vehicles will increase electricity demand for the first time in decades. See the figure below to compare California and the United States electricity consumption per capita.

Figure 10



Fossil fuels continue to represent the majority of electricity generation for the US as a whole, but renewably generated electricity is on the rise. In 2000, fossil fuels generated 24,833 billion kWh compared to 23,055 billion kWh in 2016.³⁰ The amount of renewable energy generated in 2000 totaled 1,787 billion kWh but in 2016 totaled 3,012 billion kWh.³¹ (Appendix: Electricity Patterns) This increase in renewable energy is also reflected in California's electricity production as described in Figure 6.

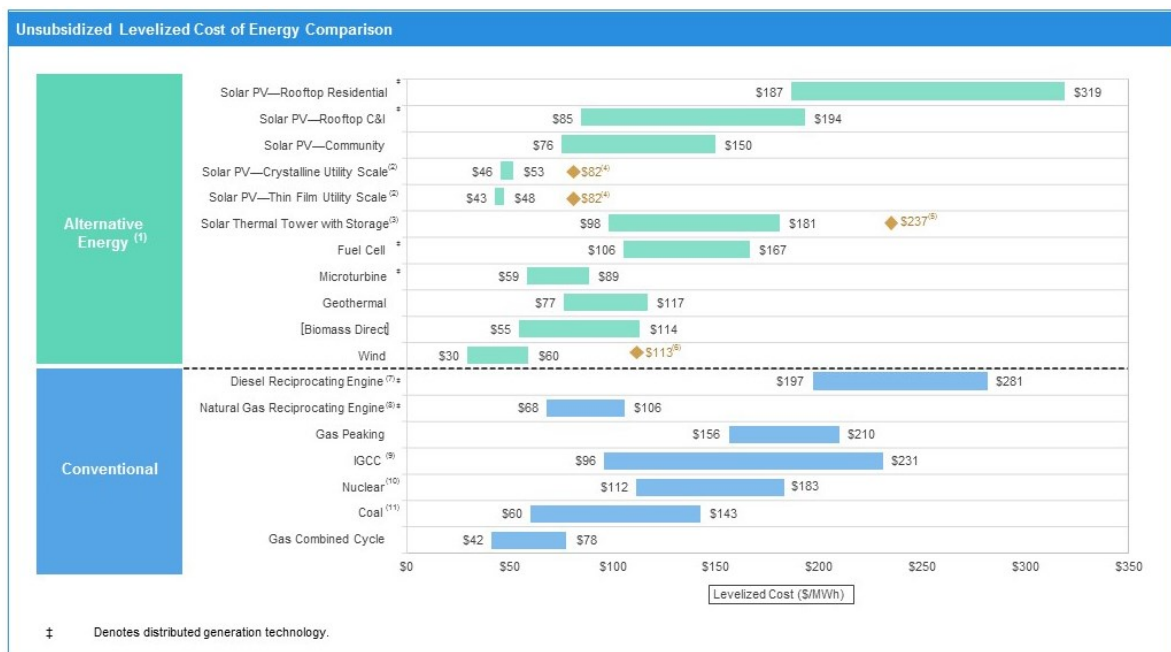
This shift to renewables is due in part to emission reduction goals for individual states and in part to the increasingly cost competitive nature of renewables as compared to fossil fuels. The 2017 levelized cost of energy reflects this change in its prices for utility scale crystalline photovoltaic solar, wind, and natural gas. Utility scale

³⁰ March 2018 Monthly Energy Review

³¹ March 2018 Monthly Energy Review

photovoltaic systems levelized cost is between \$46-\$53/MWh versus new coal which is between \$60-143/MWh, new natural gas which is \$68-\$106/MWh and gas combined cycle which is \$42-\$78/MWh.³² Due to its lower overall cost, more renewable power will continue to be implemented in the US electricity market in coming years as outdated power plants shut down and new plants are required. See more information on energy levelized cost in Figure 11.

Figure 11



Photovoltaics

According to an Economic Model for Residential Energy Consumption, the most economically beneficial system for the residential sector relies on a combination of electricity production, storage and net metering.³³ This would include a grid tied

³² Lazard

³³ Fikru, Mahelet G

photovoltaic system directly feeding the residence and a battery to store the generated electricity if it is unable to be utilized at the time it is created. This decreases the amount of electricity flowing back to the grid and allows the existing utility infrastructure to operate as normal. The CA electrical grid is currently stressed due to the existing rate of renewable penetration. Therefore, any proposed increase in renewable generation systems would need to be accompanied by a storage option.

The state's goal of increasing the renewably generated electricity will have consequences for the electrical grid regardless of the increase in electric vehicles. This has already been experienced in Germany which can be utilized as a practical example of what CA must do to prepare for this electricity shift. Some sources suggest the need for updating electrical grid lines and transformers to accommodate the increase of renewable generation or curtailing the amount of electricity renewable systems are allowed to send back to the grid.³⁴ Curtailment is common in Germany whereby photovoltaic systems are shut off if the electricity they feed the grid exceeds the grids capabilities.

This has already occurred in California due to the existing interconnected renewable generation which can outperform the needs for the state under the right circumstances.³⁵ This over production is dangerous for the electric grid and should be avoided.³⁶ If renewable generation is not shut off, extra power may be sold to neighboring states.³⁷ California Independent Systems Operation (CAISO) has been documented to pay its neighboring states to take the extra production in order to

³⁴ Von Appen, Jan & Hoppmann , Jeroen (Multiobjective Battery Storage to Improve PV)

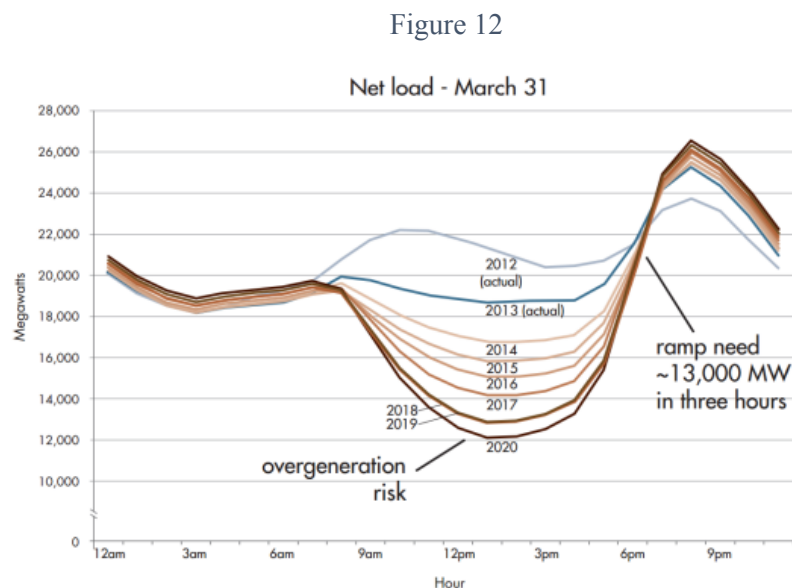
³⁵ Penn, Ivan & California ISO

³⁶ Olsen, Arne

³⁷ Penn, Ivan

safeguard the equipment and not overload the existing infrastructure. Adding additional energy storage would allow the utilities to keep the extra power without having to pay to send it out of state. As consumers continue to go solar and the state pushes towards its generation goal, this problem will occur more frequently.

Due to this increased need for energy storage in California, additional policy measures must be implemented to encourage homeowners to install storage systems along with photovoltaic systems. Battery systems can absorb the electricity generated by a household's photovoltaic system and regulate the amount of power sent back to the grid.³⁸ This overgeneration discussed is common in the state and can be linked to a term coined the "California Solar Duck".³⁹ See Figure 12 below.



As this Figure suggests, the amount of existing and projected future photovoltaics directly effects the existing grid, showing a potential risk for overgeneration at the 12,000 MW marker. In the curve showing estimates for 2020, the state's usage drops to 12,000

³⁸ Penn, Ivan

³⁹ Denholm, Paul

MW between 12pm-3pm and then increases to 26,000MW by 6pm. Both of these occurrences cause problems for utilities and the grid infrastructure. The number of existing photovoltaic systems in California as shown here drastically lowers the electricity consumption during day time hours. This proves difficult for utilities as they must shut off production methods to balance the grid. As the sun sets, people return home and utilities are impacted twice with lower solar production figures and increased consumer usage. The implementation of storage would create an opportunity to balance the “Duck” or decrease the power flowing back into the grid and generate more self-sustainment between the 6pm-9pm consumption peak.

Photovoltaic generation happens during the most expensive electricity periods which is currently a benefit for consumers. The household can use the electricity as it is generated or send it back to the utility to sell at the higher cost. The peak pricing for CA utilities is between 3pm and 9pm (PG&E) and 12pm to 9pm (SoCal Edison) on weekdays.⁴⁰ This was established in parallel to human consumption patterns as most activity occurs during the day and is shut off at night. The off peak lower prices at night allow existing electric vehicle owners to charge their vehicles at a lower price per kilowatt hour. Due to these pricing structures, utilities are not only struggling with an over generation of power during the day but are seeing less real-time consumption at those profitable peak times.

Storage Systems

⁴⁰ Pacific Gas and Electric Company & Southern California Edison

On March 15, 2018, California entered the 5th and final stage of the Self Generation Incentive Program (SGIP) that provides financial incentives to battery storage purchases.⁴¹ A study by Joern Hoppmann found that residential storage solutions will continue to need financial assistance in the short run but as prices continue to decrease, they will eventually be cost effective for residences.⁴² Due to its importance in grid stability, the state of CA should reinvest and not let the SGIP expire. Without continued investments in residential and utility energy storage, utilities will need to curtail renewables on an increasing scale.⁴³

The suggested increase in photovoltaics systems in this report would exacerbate this existing overgeneration problem, forcing utilities to curtail generation systems or run them at a loss. The large shift between 3pm and 6pm presents its own problems, forcing the utilities to generate immense amounts of power during a short period of time, ramping up their existing generation quickly using Peaker plants that are heavy carbon dioxide emitters.

It is because of these grid instability issues that this report suggests the implementation of battery systems along with increased photovoltaics capacity. If additional residential electricity production could be stored locally, it could be utilized during this 3-hour transition to allow the utilities more control in meeting electricity demand. Moreover, even without the addition of photovoltaics systems, the existing

⁴¹ Program Metrics

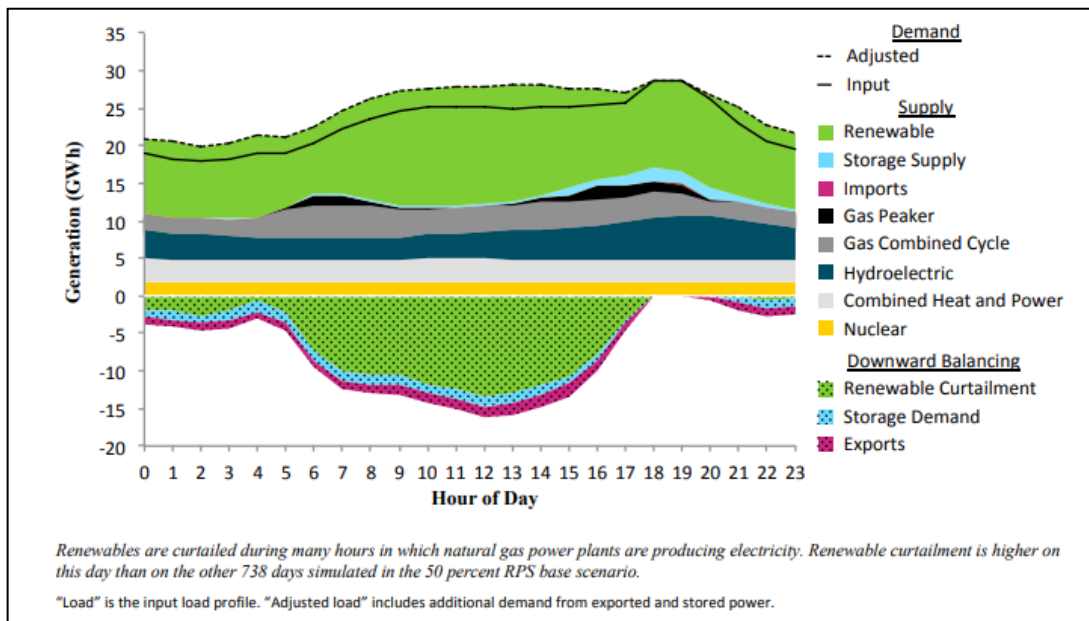
⁴² Hoppmann, Joern

⁴³ Wisland, Laura

California grid cannot continue to function in its current capacity if storage is not heavily invested in at a utility and/or residential level.

The Union of Concerned Scientists created the Figure 13 below which illustrates what the state's electrical grid may look like at 50% renewably generated power.⁴⁴ Storage does prove to be a factor here, though this current report would suggest that storage is more important than this image depicts in keeping the integrity of the grid. There is a large amount of curtailment as seen in the checkered green in the negative generation area of the chart. If this power could be stored instead of curtailed, less overall electricity would need to be generated.

Figure 13



While increasing the state's storage capacity is key, it will certainly come at a cost for utilities and their rate payers. Incentivizing consumers to change their electricity

⁴⁴ Nelson, James H

habits to better suit utility production is also an option being explored in California and would be less costly overall than forcing utilities or residences to invest in storage options. San Diego Gas and Electric (SDG&E) recently changed its rate plans so that their peak price is now in the mid evening after the sun goes down. This shift is in direct response to the number of customers with solar systems who generate power and rely on the utility to pick up the generation when their photovoltaic systems shut off. Under their new rules, the price between 4pm to-9pm is double the price from 9pm until 4pm the next day.⁴⁵ Depending on its success, other utilities may follow suit in which case a battery would be the best defense for customers with photovoltaics to avoid the high tiers that occur after their system has shut off for the night thereby convincing consumers to make the shift in demand on their own.⁴⁶ Either way, the ultimate cost will fall on the consumer for purchasing their own battery or paying higher utility rates for utility battery investment.

Utility companies may also determine that investing in residential battery storage is the most economical solution to combat increased photovoltaic generation. Tesla Inc and Vermont's utility Green Mountain Power are piloting a program to dispense Powerwall battery systems residentially and allow consumers to purchase them at a discounted rate. In exchange, the utility has the ability to send power back into the grid from the battery when demand is at its peak thereby relieving stress for the utility grid while providing consumers low cost battery solutions.⁴⁷ This option claims to be the first in a pilot program for Tesla, and if it is successful, more of these programs may be seen

⁴⁵ Rice, Dave

⁴⁶ Nikolewski, Rob. "'Time of Use' Rates for Solar Customers May Give Batteries a Boost

⁴⁷ Green Mountain Power

around the country. This is another way that utilities may try to combat local deficiencies in power without needing to invest in large photovoltaic arrays or battery storage.

As is discussed in Tyagunov, Mikhail's report, distributed power is projected to be the future of electrical systems.⁴⁸ This cannot occur without storage to deliver the power when and where it is needed. Large storage is feasible as seen in Australia with the Hornsdale wind farm which now has a battery storage capacity of 100 MW.⁴⁹ There are many other large battery installations that are proving beneficial for communities that are not interconnected to a large electricity grid. Puerto Rico for example is relying currently on multitudes of micro grids that contain photovoltaics and battery storage due to the most recent hurricane season which destroyed the majority of their infrastructure.⁵⁰ The Hawaiian island of Kauai recently built a 13 MW photovoltaic farm with 52 MW of battery storage in order to decrease the reliance on diesel brought to the island by ship.⁵¹ These examples illustrate the fact that storage is a necessary part of electric grid security and also illustrate the possibility for a grid to become more than 50% renewable.

According to work extrapolated from the Ecologic Vehicles Renewable Energies report, installing battery systems would help absorb the amount of power generated through the proposed number of photovoltaic systems, and level out the states demand for electricity.⁵² Batteries would be able to interact with the existing grid and smooth out the peaks and valleys experienced by consumer usage. The report explains that a residential battery can be designed to allow for consumption to be pulled from the grid up to a

⁴⁸ Tyagunov, Mikhail

⁴⁹ Etherington, Darrell

⁵⁰ Martin, Chris

⁵¹ Golson, Jordan

⁵² Haines, Gareth

certain threshold, and anything that demands additional power would be taken from the battery itself. When the household demand falls below the threshold, the battery charges itself leading the home to utilize power at a flat demand instead of peaking when power is used and dropping when it is not. Similar reports suggest that the implementation of battery storage residentially will lead to an increase in power plant efficiency due to this and decrease the wear and tear on utility equipment because of the decrease in alternating demands.⁵³

The hypothesis of a report by Paul Jennings⁵⁴, a report by Xiaohua Wu⁵⁵ and a report by Kristien Clement-Nyns⁵⁶ suggests that the electric vehicles can be utilized as home storage option as well. This suggests that with the addition of electric vehicles into the electrical grid, the demand can be smoothed out and consumption habits more easily predicted. Multiple studies from the aforementioned authors as well as Rodica Loisel⁵⁷ confirmed that while battery storage is useful to store electricity from photovoltaic systems, the addition of an electric vehicle to a home with or without photovoltaic increases the homes ability to flatten out the homes demand.

⁵³ Dunn, Bruce

⁵⁴ Haines, Gareth

⁵⁵ Wu, Xiaohua

⁵⁶ Clement-Nyns, Kristien

⁵⁷ Loisel, Rodica

The vehicles themselves can be used to feed power back into the home at high peak demand times if the customer is present in the household. This is possible with all electric vehicle battery systems and even plug in hybrid systems according to Gareth

Figure 14

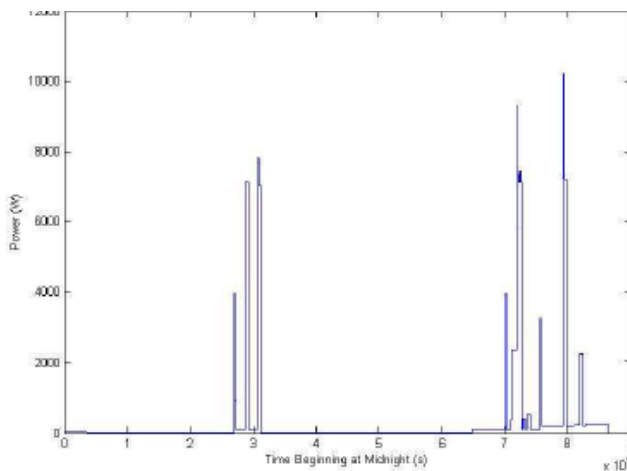
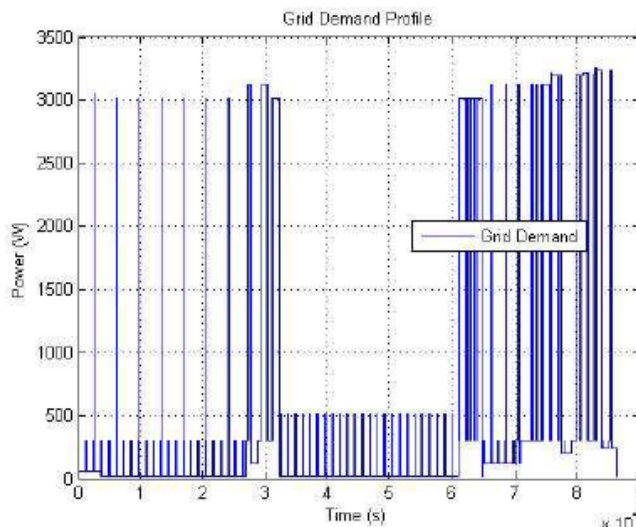


Figure 15



accomplish the same goal despite the number of miles driven daily.

If consumers were to utilize specific home storage in the form of a battery system, they would be able to charge their vehicles from the battery which would also accomplish the smoothing of the utility usage to a larger degree than the utilization of an electric

Haines, but it remains dependent on the number of miles traveled daily and the battery's state of charge. The higher the daily commute, the less power available to offset grid usage. This report goes on to state that if a consumer utilizes their electric vehicle for longer than 15 miles a day, its assistance as a home energy battery is greatly decreased. If these households also equip themselves with an independent battery system as this report has suggested, they would be able to

vehicle's battery system. See the Figures above. Figure 14 shows the home electricity demand with no electric vehicle or battery system and the Figure 15 shows the grid demand for a home that has an electric vehicle and charges any large appliances over 3kW with the electric vehicles battery system. When the home falls under 500W, it is assumed that the homeowner is not present, and that therefore the battery is not charging.

From the findings discussed above, it can be concluded that the existing grid infrastructure may be set up for success in delivering the increased amount of power to consumers with the increased density of electric vehicles. The caveat for these findings is that with California's renewable energy goals, any additional demand by the homes would need to be offset using battery storage systems and renewable power. This report does not discuss the utility's infrastructure such as the transmission lines or substations. Not enough information was discovered regarding this material to draw any solid conclusions. However, it is notable that the use of the CAISO data suggests that an increase in electric vehicles may be beneficial for the utilities as it will increase the amount of residential consumption.

If electric vehicles had the ability to charge during the day when all of this power is being generated, it may provide some relief for the utilities as it would increase the daily demand, but electric vehicles, like all vehicles are generally driven to a person's place of work and left there until they return home. To ask consumers to charge their vehicles during the day would require a significant amount of public education and the addition of electric vehicle infrastructure to more work places. A more straightforward path forward is the installation of battery systems residentially or on a utility scale. If even a percentage of the battery storage discussed here were to be installed into the CA

grid, it would be able to decrease renewable curtailment and utilize this power during the three-hour high demand according to the “Solar Duck”. This would allow the CA grid to utilize all renewable power being generated instead of being forced to send it out of state or turn off renewable generation to protect the grid.

At this time, the federal incentives for electric vehicles expires after the sale of 200,000 electric vehicles per manufacturer.⁵⁸ Reports suggest that this benchmark is fast approaching, and increased incentives will be necessary to continue to electrify the countries fleet. Tesla for example is scheduled to reach 200,000 vehicles sold in the second quarter of 2018.⁵⁹

Previously reviewed in this document was the fact that US has increased its electricity efficiency so that per capita, consumers use less power than was used in 1980. In consideration of this and the increasing growth of residential photovoltaic systems, utilities have faced a stagnant market with little growth. The increased sale of electric vehicles bodes well for utilities as it will boost their usage and may be able to smooth out residential consumption habits. Due to this, utilities are already taking a stand to push government forces to continue offering electric vehicle incentives.⁶⁰ In March 2018, PG&E announced an additional \$10,000 rebate for electric vehicles.⁶¹ These incentives should be extended due to their support of a market that beneficial for the environment.

In conclusion, the state of California is increasing its electric vehicle fleet annually and is expected to reach a density of one electric vehicle per household by

⁵⁸ EV: Tax Credits and Other Incentives

⁵⁹ US Federal \$7,500 Electric Vehicle Credit Expiry Date By Automaker

⁶⁰ Salisbury, Mike, and Toor, Will

⁶¹ Walton, Robert

around the year 2081. This annual increase in electric vehicles will lead to increased electricity demand for the state which has experienced a yearly decrease in total consumption and consumption per capita since early 2000. This increase in demand should be offset with renewable generation in order for the state to reach its 50% renewable power by 2030 goal. However, in order to allow the existing grid infrastructure to accept the renewable energy, additional energy storage must also be deployed on a residential or utility scale.

Renewable energy curtailments are already being experienced in the state due to the over generation of renewable energy. If California were able to capitalize on this renewable energy when it is produced, it would be better prepared to provide electricity for its consumers and rely less on more expensive dirtier fossil fuels. California is a renewable energy leader in terms of policy and adoption, and though the state continues to increase its renewable energy portfolio, it must invest more heavily in storage to better manage its renewable energy production.

CA must also continue to expand its rebates and incentives for electric vehicles, home storage and photovoltaic systems. The existing SGIP is beneficial in encouraging more residents to buy storage, and with the current state of our utility grid, this incentive should be renewed for years to come. Increased electricity storage is the only path forward that will allow CA to reach its goal of 50% renewable energy without a utility mandated infrastructure overhaul.

VI. Appendix Attached

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VIII. Curriculum Vitae

Jayne Callander | San Francisco, CA | jaynecallander@gmail.com | 415-710-3249

Education:

Johns Hopkins University, Baltimore, MD

2016- 2018

Master of Science in Energy Policy

Capstone Project: Electric vehicles in California: offsetting increased electricity demand with photovoltaics and energy storage

Loyola Marymount University, Los Angeles, California

2009- 2013

Bachelor of Arts Major- English Minor- Political Science

Experience:

Tesla Energy (formerly SolarCity)

Business Resolution Supervisor

2017-Current

Directly manage team of 5 analysts responsible for customer escalations. Responsible for hiring, training, and annual performance evaluation process. Manage the approval process for research, analysis and recommendation of analysts as well as all Settlement

and Release of Claims legal documents. Working closely with design, engineering, finance, and legal. Addressing problematic sales processes and techniques. Root cause analysis for high level customer escalations.

Business Resolution Analyst 5/16- 9/17

Investigate customer escalations and provide customer support. Draft legal Settlement and Release of Claims documents. Developed detailed models to project customer monthly savings and developed sales recommendations.

Reassignment Agent 5/15- 5/16

Manage a portfolio of 150 properties, resell existing solar contracts and negotiate contract changes with customers. De-escalate frustrated customers. Create contract amendments. SolarCity Women in Power Recruitment Team: Attend recruitment events and promote female applicants.

Junior Reassignment Agent 1/15- 5/15

Transferred existing SolarCity contracts from homeowner to homeowner. Educated real estate agents, home owners, and buyers on SolarCity contracts. Negotiated contracts with future customers. Managed a portfolio of 100 properties and customers.

Reassignment Coordinator 7/14-1/15

Assisted agents with the real estate process including speaking with escrow, buyer, and seller's agents. Trained incoming coordinators.

Field Energy Specialist 8/13-6/14

Named one of top three female sales representatives for 10 continuous months. Generated solar sales leads in Home Depot stores. Utilized Salesforce.com and Microsoft Outlook software. Consistently exceeded monthly quota. Trained sales associates and public Speaker for lead generation sales team conference.

Project Development Intern 5/12-8/12

Created pipeline for commercial sales department. Generated \$15 million in sales through water agencies. Conducted research through cold calling over 250 water agencies. Wrote a 50 page research paper "California Water Agencies and Energy Trends". Created strategies for target audiences including school districts and water agencies.

Municipal Water District of Orange County 10/ 12-8/13

Public Relations Intern

Drafted press releases and responded to customer calls. Created educational papers for public use on water quality. Organized public-school events on water conservation and planned public educational tours. Posted weekly on social media forms such as Facebook, Twitter, and Pinterest and addressed public concerns through social media posts.